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TECHNICAL REPORT ARCCB-TR-95002

FATIGUE LIFE AND FRACTURE ANALYSES FOR THE M185/M284 BREECH RING

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JANUARY 1995

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1995	Final

4. TITLE AND SUBTITLE
FATIGUE LIFE AND FRACTURE ANALYSES
FOR THE M185/M284 BREECH RING

5. FUNDING NUMBERS
AMCMS No. 6126.24.H180.0
PRON No. LT3A3FUS1ABJ

6. AUTHOR(S)
J.H. Underwood, E. Troiano, and A.A. Kapusta

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Benet Laboratories, AMSTA-AR-CCB-O
Watervliet, NY 12189-4050

8. PERFORMING ORGANIZATION REPORT NUMBER
ARCCB-TR-95002

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Close Combat Armaments Center
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Fracture mechanics and fatigue life analyses were performed for M185/M284 breech rings, with emphasis on ring Serial No. 1659, which failed during safe life testing after 109 pressure cycles. Mechanical and fracture properties from the breech rings were measured and used to perform yield-before-break fracture analysis. Scanning electron fractography was used to determine the size of defect present in ring Serial No. 1659 prior to laboratory testing and the types of cracking that occurred during laboratory testing. Mean fatigue life calculations were prepared for various sizes of defect and applied pressures, including the defect size measured from fractography, the pressure of the laboratory test, and the pressure of the rounds that are fired with this type of breech ring.

14. SUBJECT TERMS
Fatigue Life, Laboratory Tests, Cannon Breech,
Fracture Toughness, Electron Microscopy

15. NUMBER OF PAGES
15

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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ACKNOWLEDGEMENTS

The authors are pleased to acknowledge the help of R. Farrara, R. Abbott, E. Leighton, R. Lasselle, and D. Corrigan, all of Benet Laboratories, during various stages of this work.

INTRODUCTION

The failure of M185/M284 breech ring Serial No. (S/N) 1659 after only 109 pressure cycles of safe fatigue life testing prompted three pieces of work: a failure analysis by Thornton et al. (ref 1), a fracture analysis by Troiano (ref 2), and the work reported here. Thornton and coworkers concluded that ring S/N 1659 failed from a 0.5-mm deep crack in a brittle manner due to an improper heat treat and a resulting undesirable microstructure. Troiano measured mechanical and fracture mechanics properties of ring S/N 1659 and two other rings, and showed that the fracture behavior of ring S/N 1659 was markedly different from that of the other rings. The work here uses the prior work and additional fracture tests and analyses to calculate fatigue lives of the M185/M284 breech ring with cracks of various depths and with various applied pressures.

Fracture mechanics and fatigue life analyses were performed and compared with laboratory test results for three M185/M284 breech rings: S/N 1659, S/N 1623, and S/N 2101. Mechanical and fracture properties from the breech rings were measured and used to perform yield-before-break fracture analysis. Scanning electron fractography was used to determine the size of defect present in ring S/N 1659 at the start of tests and the types of cracking that occurred. Mean fatigue life calculations were prepared for various sizes of defect and applied pressures, including the defect size measured from fractography, the pressure of the laboratory test, and the pressures of the rounds that are fired with this type of breech ring.

A brief summary of some important results of the safe fatigue life testing of the M185/M284 breech ring is shown in Figure 1. This summary shows how strikingly different the results were for S/N 1659, compared with other results of the safe fatigue life tests. Note that both the critical crack depth at the final fatigue failure, a_c, and the laboratory fatigue life, N_{lab}, are markedly different for S/N 1659 compared with the two other rings.

MECHANICAL AND FRACTURE PROPERTIES

Table 1 and Figure 2 summarize the mechanical and fracture mechanics results obtained from the three rings. The only results that were essentially equivalent for ring S/N 1659 and the other two rings were ultimate strength and hardness. The 0.2 percent offset yield strength for S/N 1659 was 70 percent of the average value for the other two rings. This significantly lower yield strength is often a sign of an improper heat treat; this supports the Reference 1 conclusions regarding heat treat and microstructure. The fracture toughness of S/N 1659, as measured by either -40°C Charpy energy or by K_J (the critical K from a J_{Ic} test) was also considerably lower than that of the other two rings. This is again consistent with the Reference 1 results. A graphic comparison of the very significant differences between S/N 1659 and the other rings is shown in Figure 2, which shows two of the load versus displacement plots used to determine K_J for S/N 1659 and S/N 1623. Fracture toughness is directly related to the area under this type of load-displacement curve, and it is clear that the area under the curve for S/N 1659 is much smaller than that for S/N 1623.

It is important to note from the mechanical and fracture properties in Table 1 that it is not possible to separate the low toughness S/N 1659 ring from rings with adequate toughness by using the hardness results. Although hardness is a useful screening test for some types of materials, it is clearly of no use here to separate high from low fracture toughness. This is confirmed further by the ultimate tensile strength results, which in nearly all materials are directly related to hardness results. The ultimate strength results are not significantly different for specimens with very significant differences in fracture toughness. This information and, more importantly, information on the magnetic properties of these various breech ring materials are being used in field screening tests to identify any additional rings with inadequate fracture toughness.

YIELD-BEFORE-BREAK ANALYSIS

Recent work at Benet Laboratories (ref 3) has provided a method for determining the severity of the final fatigue failure of cannon components. The method was used in this work to determine how severe the failure of S/N 1659 was in relation to the other two rings and to other cannon components. Results are shown in Table 2 and Figure 3. Table 2 lists the crack depth at failure, a_c, and the size of the remaining uncracked ligament ahead of the crack, b_c, measured from the fracture surface after the test. The yield-before-break method (ref 3) calculates a plane-strain ligament, $(K_J/Sy)^2$, and compares it with the measured b_c. The fracture toughness, K_J, and yield strength, Sy, are the mean values from Table 1. A running crack is observed when b_c is large relative to the plane-strain ligament, whereas a safe yield-before-break final failure is observed when b_c is small relative to the plane-strain ligament. In equation form, yield-before-break failure is expected when

$$b_c < (K_J/Sy)^2 \tag{1}$$

Figure 3 shows the yield-before-break analysis of the three breech rings compared with cannon tube results from Reference 3. Note that a running crack is clearly indicated for ring S/N 1659, whereas a yield-before-break failure is indicated for rings S/N 1623 and S/N 2101. This agrees with the safe life testing experience for these three rings and shows that the fracture toughness and yield strength of a ring can be used to indicate the type of fracture that will occur in testing.

SCANNING ELECTRON FRACTOGRAPHY

Figures 4 through 7 show results of scanning electron fractography on the fracture surface of ring S/N 1659. Figure 4 is a 100X photo of the failure site, showing the edge of the ring, a light oxide coating extending about 0.4 mm in from the edge, and a change from predominant fatigue failure to predominant cleavage failure at about 0.5 mm in from the edge. The 0.5-mm extent of fatigue failure is in good agreement with the results of Reference 1. The 0.4-mm deep oxide layer indicates that a fatigue crack was present in the ring before safe life testing at Benet Labs.

Figures 5 through 7 are 1000X photos of the fracture surface of S/N 1659 at progressively larger distances below the surface. Figure 5 shows fatigue with a predominance of oxide, Figure 6 shows fatigue with traces of oxide, and Figure 7 shows cleavage failure with no oxide. These results are consistent with a fatigue crack growing slowly due to field firing, growing more rapidly in the field, and failing very rapidly in laboratory testing by cleavage.

CALCULATED MEAN FATIGUE LIVES

The classic fracture mechanics method for calculating fatigue life follows (ref 4). Starting with the experimentally determined relationship for fatigue crack growth rate in gun steels

$$da/dN = 6.52 \times 10^{-12}\, \Delta K^3 \tag{2}$$

where da/dN is in m/cycle and ΔK is in MPa$\sqrt{m}$, and then integrating gives

$$N = [1/\sqrt{a_i} - 1/\sqrt{a_c}]/1.2 \times 10^{-9}\, P^3 \tag{3}$$

In Equation (3) a_i is the initial crack depth, a_c is the final crack depth (typically the critical crack depth), the constant 1.2×10^{-9} is determined from Equation (2) and from the K relationship for this loading and configuration, and P is the firing or lab test pressure. The critical crack depth was determined using the K relationship

$$K = f P \sqrt{a} \tag{4}$$

where $f = 7.16$ and accounts for the loading and configuration.

Equations (3) and (4) were used to calculate the critical crack size and fatigue life for various values of pressure, P, and initial and final (critical) crack depth, see Table 3. The pressure of the laboratory safe fatigue life tests, 393 MPa, was used, as were pressures corresponding to the M119, M4, and M3 rounds. Critical crack depths were calculated from Equation (4) using these pressures and the mean fracture toughness for ring S/N 1659, which was 63 MPa$\sqrt{m}$. Two values of a_i were used: 0.4 mm, the value determined from Figure 4, and 5 mm, an assumed depth believed to be possible in a fired ring. The rationale for this assumption is that 5 mm is smaller than the critical crack for all but two of the round pressures listed in Table 3. The value of a_c from Equation (4) was used for all life calculations.

Note the following aspects of the calculated fatigue lives listed in Table 3.

For a_i = 0.4 mm and the lab test pressure, the calculated life of 70 cycles is in good agreement with the measured life, 109 cycles. If a_i = 0.36 mm were used, the agreement would have been nearly perfect. These results show that the life calculation method gives reasonable results.

For a_i = 0.4 mm, the M119 and the M4 zone 7 rounds result in lives below 5000 cycles. This indicates that extended firing of a ring similar to S/N 1659 using these round/zone combinations should be treated with caution.

For a_i = 5 mm, the M119, the M4 zones 6 and 7, and the M3 zone 5 rounds result in lives below 5000 cycles. This indicates that extended firing of a ring with a 5-mm deep crack and 63 MPa$\sqrt{m}$ fracture toughness using these four round/zone combinations should be treated with caution.

CONCLUSIONS

1. The markedly low fracture toughness of ring S/N 1659 causes an unsafe running crack failure, as opposed to a safe yield-before-break failure for other rings with the expected level of fracture toughness.

2. The low fracture toughness rings cannot be distinguished from rings with adequate toughness by using hardness or ultimate tensile strength test results.

3. Scanning electron fractography showed that a preexisting 0.4-mm deep crack was present in ring S/N 1659 before safe fatigue life testing, and that the preexisting crack caused the very low fatigue life of 109 cycles. Fractography also showed evidence of fatigue failure to a depth of 0.5 mm below the surface and evidence of cleavage beyond the 0.5-mm depth.

4. A method of fatigue life calculation was developed that agreed well with the 109-cycle life of ring S/N 1659, and that was used to predict lives for a ring with given values of applied pressure and preexisting crack depth.

5. Extended firing of a ring with fracture toughness similar to that of ring S/N 1659, containing a 0.4-mm deep crack, and using the M119 and the M4 zone 7 rounds should be treated with caution.

6. Extended firing of a ring with fracture toughness similar to that of ring S/N 1659, containing a 5-mm deep crack, and using the M119, the M4 zones 6 and 7, and the M3 zone 5 rounds should be treated with caution.

REFERENCES

1. P. A. Thornton, J. R. Senick, K. E. Noll, and D. B. Moak, "Failure Analysis of RCMAS Breech Ring S/N 1659," Memorandum for Record, Benet Laboratories, Watervliet, NY, 8 February 1993.

2. E. Troiano, "Fracture Analysis of 155-mm M185/M284 Breech Rings S/N 1659, S/N 2101, and S/N 1623" Memorandum for Record, Benet Laboratories, Watervliet, NY, 28 February 1993.

3. J. H. Underwood, R. A. Farrara, and M. J. Audino, "Yield-Before-Break Fracture Mechanics Analysis of High Strength Steel Pressure Vessels," *Proceedings of ASME Pressure Vessels and Piping Conference*, Denver, CO, July 1993.

4. J. H. Underwood and J. F. Throop, "Surface Crack K Estimates and Fatigue Life Calculations in Cannon Tubes," *Part-Through Crack Fatigue Life Prediction, ASTM STP 687*, American Society for Testing and Materials, Philadelphia, 1979, pp. 195-210.

S/N	Yield Strength	Ultimate Strength	Hardness	Charpy Energy (-40C)	Fracture Toughness
	MPa	*MPa*	*HRC*	*J*	*MPa√m*
1659	703	1270	37	10	62
	710	1262	37	5	64
1623	1014	1240	37	26	114
	958	1172	37	34	121
2101	1034	1282	38	15	116
	1048	1310	38	16	109

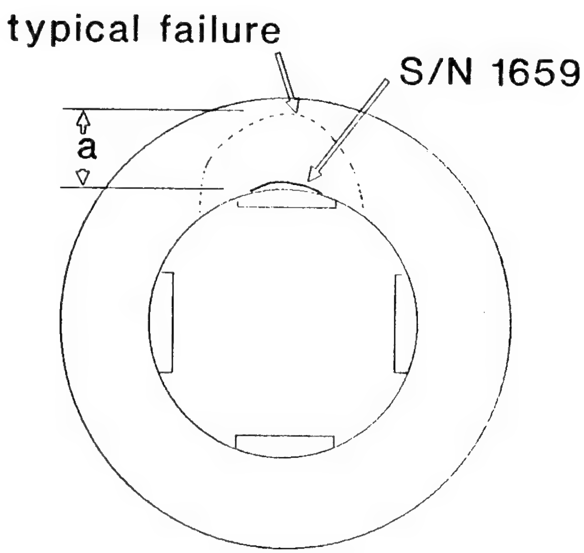
Table 1 Measured Material Properties

S/N	Crack Depth at Failure a_c *mm*	Mearured Ligament at Failure b_c *mm*	Calculated Plane Strain Ligament $(K_J / Sy)^2$ *mm*
1659	0.5	49.5	8
1623	45	5	15
2101	40	10	12

Table 2 Yield-Before-Break Analysis

Round/Pressure	P MPa	Critical Crack a_c mm	Calculated Mean Fatigue Life N; a_i = 0.4mm *measured*	N; a_i = 5mm *assumed*
LAB	393	0.50	70	1
M119	214	1.69	2,190	1
M4z7	173	2.60	4,940	1
M4z6	110	6.35	23,200	990
M4z5	72	14.8	91,500	12,900
M4z4	52	28.9	265,000	49,700
M4z3	41	45.2	532,000	110,000
M3z5	107	6.77	25,800	1,360
M3z4	62	20.1	149,000	24,700
M3z3	55	25.4	217,000	39,000
M3z2	45	38.5	415,000	83,600
M3z1	35	65.1	935,000	207,000

Table 3 Calculated Mean Life Results



	a_c mm	N_{lab} cycles
S/N 1659	0.5	109
S/N 1623	45	5125
S/N 2101	40	4444

Figure 1 Summary of Tests and Analyses

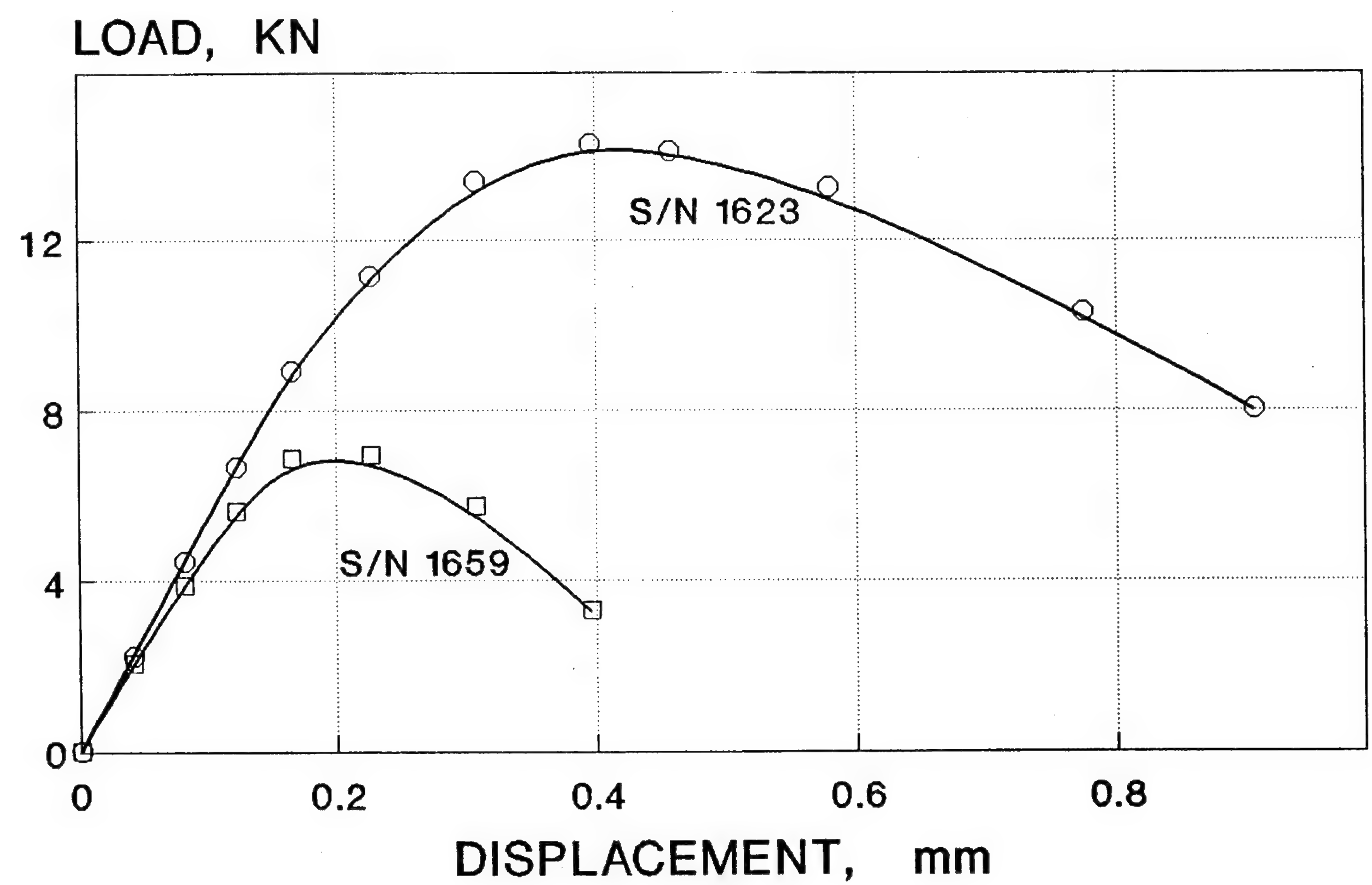


Figure 2
Load-Displacement Plots for J_{Ic} Tests
of Two M185/M284 Breech Rings

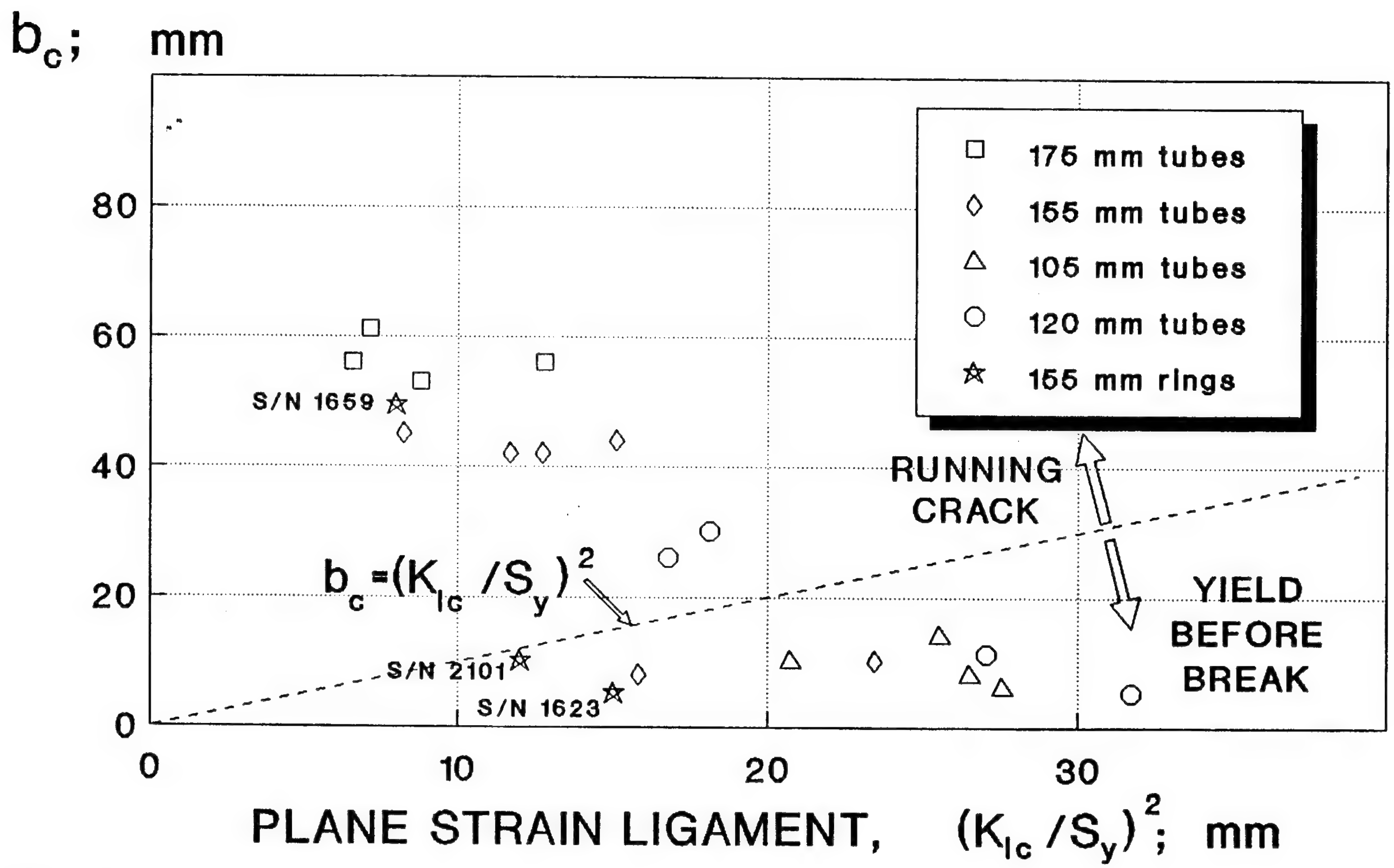


Figure 3
Yield-Before-Break Analysis of Breech Rings Compared with Cannon Tubes

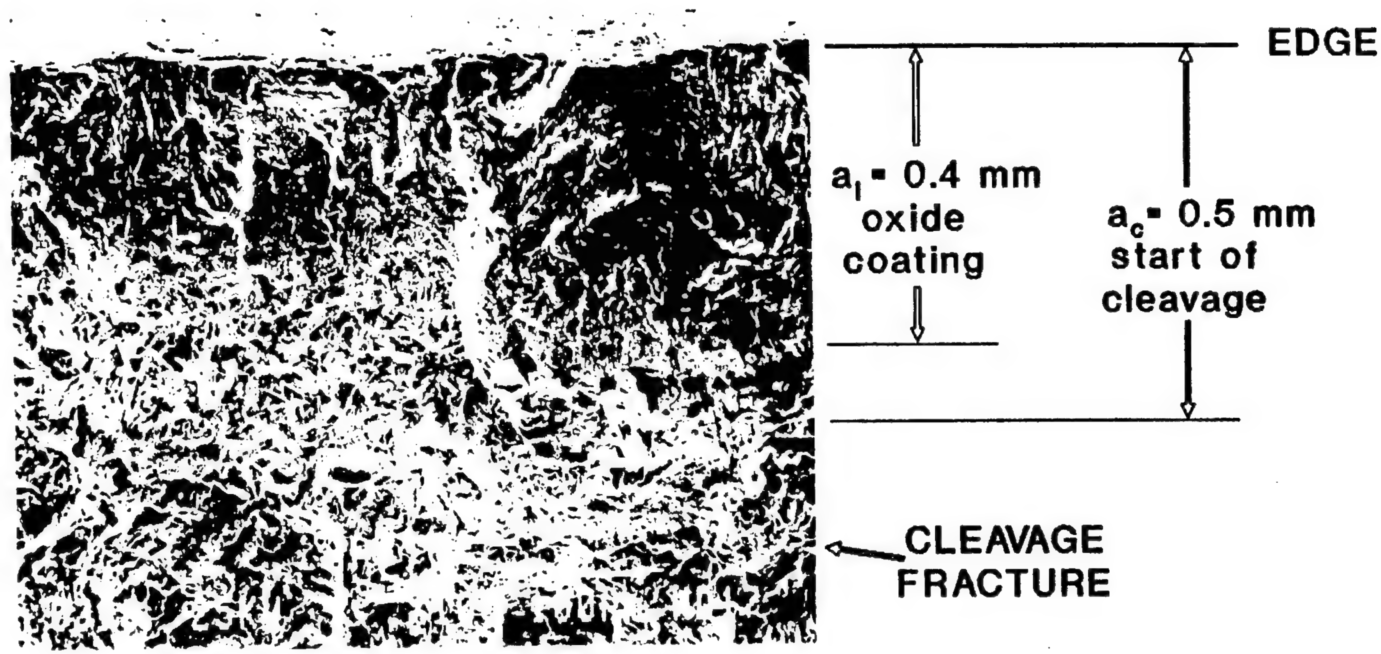


Figure 4 SEM Fractograph; S/N 1659 After Test

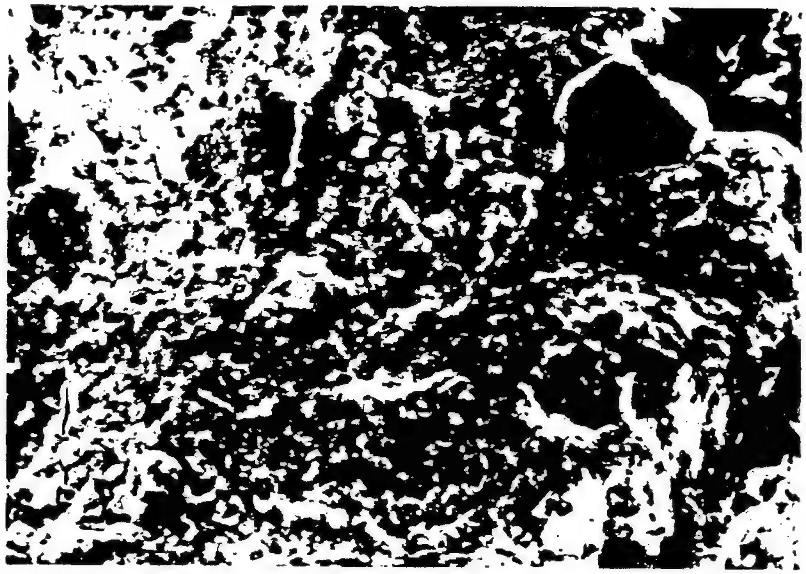


Figure 5 Fatigue Fracture with Oxide Present; 1000 X; at 0.2 mm depth

Figure 6 Fatigue Fracture with Oxide Traces; 1000 X; at 0.4 mm depth

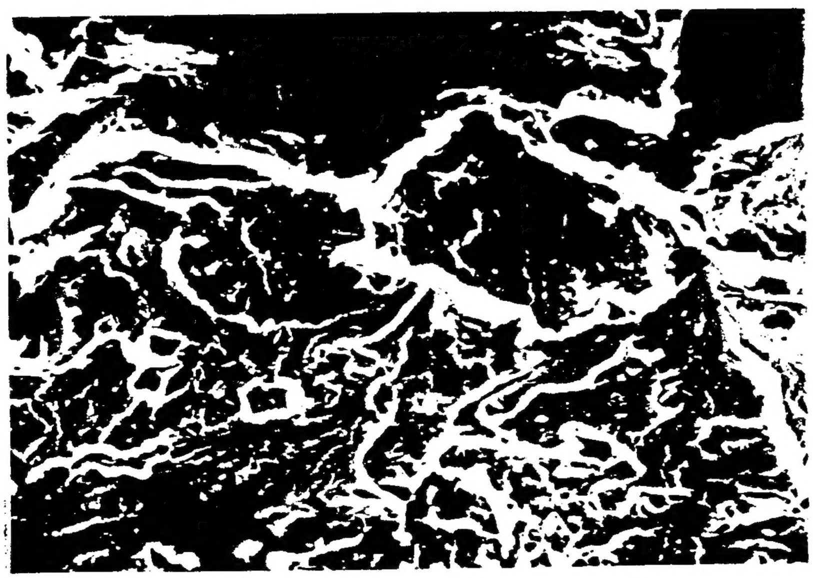


Figure 7 Cleavage Fracture; 1000 X; at 0.6 mm depth

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